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(71) Applicant: THERMODYNETICS, INC.
651 Day Hill Road
Windsor, CT 06095(US)

(72) Inventor: Sievers, Richard W.
41 Timber Trail
South Windsor Connecticut 06095(US)

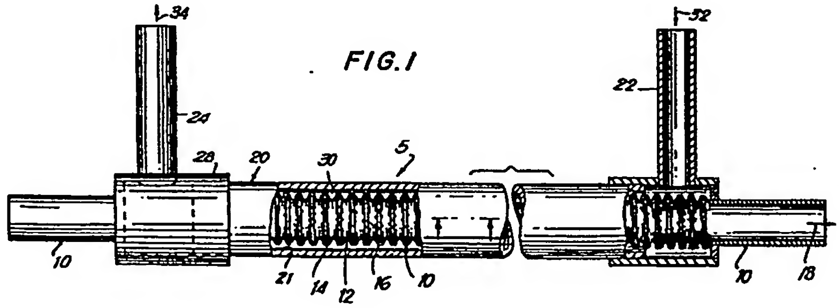
(72) Inventor: Ramachandran, Ajit K.
101 Stewart Street
Bristol Connecticut(US)

(74) Representative: Dixon, Donald Cossar et al,
Gee & Co. Chancery House Chancery Lane
London WC2A 1QU(GB)

(54) Heat exchanger.

(57) Fluid heat exchangers of various configurations are disclosed, which exhibit improved performance resulting from the use of an inner tube (10) having annular corrugations (12) which provide a substantially increased surface area. One fluid (16) flows through the inner tube which is disposed within an outer tube (20), and another fluid (30) flows through the generally annular-section passageway between the inner and outer tubes.

FIG. 1



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HEAT EXCHANGER

This invention relates generally to the field of heat exchangers, and more particularly to high performance, compact fluid heat exchangers in which annularly corrugated tubing is utilized as part of tube-in-tube, shell and tube, or coil and shell (with or without centerbodies) heat exchangers which may have straight, "J"-shape, helix or similar configurations.

Heat exchangers of many types and configurations are well known and used to transfer heat from one fluid to another, to heat, cool, desuperheat, condense, evaporate or otherwise change the thermal energy level of a fluid. Heat transfer is accomplished by placing the two fluids in sufficiently close proximity to each other so that the cooler fluid will absorb the heat from the warmer fluid. Of course the heat transfer must occur without allowing the fluids to mix since, for example, if the cooler fluid is a refrigerant, brine solution or the like and the warmer fluid potable water, mixture would render the potable water useless. Likewise the warmer fluid could be contaminated and thus must be kept out of contact with the cooler fluid to avoid its contamination.

Prior heat exchangers having similar configurations but constructed of smooth wall tubing are in-

herently limited in their heat transfer performance. At flow rates which are in the laminar range, the heat transfer of the heat exchanger is substantially proportional to the surface area of the tube. Thus, it was recognized that by replacing the smooth wall tube with a helical twisted tube, the performance of the heat exchanger increased. Such heat exchangers are exemplified by those shown in U.S. Patent No. 3,826,304 (Withers, Jr., et al.).

Heat exchanger structures made from helical twisted tubing, however, have several disadvantages. First, the percentage increase in surface area compared to smooth wall tubing is not very great. Second, the spiral tubing, although more flexible than smooth wall tubing, is still relatively difficult to form into tight configurations. Further, in certain configurations, the helical tubing provides a flow path for one of the fluids in the heat exchanger that interferes with the flow of the second fluid.

When tubing is twisted into a helical configuration by methods such as those disclosed in U.S. Patent No. 4,059,004, an inherent characteristic of the tubing so formed is that the twisted helical configuration appears along substantially the entire length of the formed tube. Such a configuration makes it difficult to fabricate certain heat exchangers in which an intermediate smooth portion of the tube is preferred.

Other early attempts to alter the surface area of the inner tube resulted in devices having raised fins or otherwise configured surfaces, which would serve to increase the surface area over which the exchange of heat is accomplished.

Finned tubed devices, however, presented other shortcomings. Although finned tubes may have relatively large surface area, such tubes are expensive to fabricate. Further, configurations of heat exchangers using finned tubes suffer from a substantial increase in the flow resistance in the area of the fins. In such case, fluid flowing over the fin direction transverse to the plane of the fin may tend to deposit any impurities or contaminants near the base of the fin in the area having the lower flow velocity. Such stagnation areas detract from the efficiency of the otherwise high-performing tube-in-tube heat exchanger.

Another problem resulting from the use of finned tubes is the loss of heat exchange efficiency due to the high thermal resistance between the tube and the fin. When fins are added to smooth tubes by welding, brazing or other fabrication techniques, the junction of the two components adds thermal resistance and lowers the efficiency of the heat exchanger.

The fins added to the outside of the tube also tend to add to the rigidity of the assembly, which is disadvantageous in the many configurations of heat ex-

changers in which flexibility of the tube is required.

It is broadly an object of the present invention to provide an improved heat exchanger which overcomes or avoids these and the other disadvantages of conventional heat exchangers formed from either smooth wall tube or twisted helical tubes and in particular to provide a heat exchanger which exhibits enhanced efficiency in the laminar flow range.

It is a further object of the present invention to provide a heat exchanger incorporating a central annularly corrugated tube with increased surface area compared to prior art heat exchangers of the same configuration. It is the further object of the present invention to provide a heat exchanger which incorporates an inner tube formed with increased surface area and therefore exhibits an overall decreased fill area. It is a still further object of the present invention to provide an improved heat exchanger which can be formed with tighter bends for a given tube diameter.

It is a still further object of the present invention to provide an improved heat exchanger with an annular corrugated tube which contains smooth walled sections to improve fabrication.

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sections to improve fabrication.

It is a still further object of the present invention to provide an improved heat exchanger with enhanced performance which is economical to fabricate.

In accordance with one embodiment of the present invention demonstrating the objects and features of the invention there is provided an improved fluid heat exchanger comprising a first tube having a passage therein, and a first and a second end, for carrying a first fluid in a first direction; a second tube disposed within said passage, and having a plurality of annular corrugations thereon, for carrying a second fluid in a second direction; an inlet connected to said first end of said first tube for introducing said first fluid to said first tube; and an outlet connected to said second end of said first tube, to remove said first fluid therefrom.

Applicants have discovered that the above-referred objects may be realized by a heat exchanger of the type described, by utilizing therein an inner tube having annular corrugations thereon.

The use of annularly corrugated tubes in the heat exchangers of the present invention provides improved heat transfer resulting from the greatly increased effective surface area of the heat exchanger boundary. Experimentation has demonstrated that the use of an annularly corrugated inner tube provides in the

range of 40-60% more useful heat transfer area (i.e., surface area) than a similar length of smooth wall tubing. This may be compared with the surface area of known twisted tubing, which provides merely 25-28% more area than smooth wall tubing. Further improvement in the heat transfer effected by the device stems from the lack of extraneous (heat) conductive material on the surface of the tube, such as in conventionally configured tubes. Only the thickness of the tubing separates the two fluids.

Other benefits stem from the use of such an inner tube.

An annularly corrugated tube is far more flexible than known tubing. Not only does this arrangement avoid the introduction of inflexible exterior configurations to the tube, but it renders the tube more flexible than a smooth tube, or even a threaded tube.

Furthermore, since the manufacture of annularly corrugated tubes is well-known, it is possible to make such tubes with flat land portions thereon, which may further serve to increase the utility thereof.

Still further benefits realized by heat exchangers manufactured in accordance with this invention will be described below in regard to specific embodiments thereof to which they may be pertinent.

The improved heat exchanger of the present invention has particular utility in the biomedical field

as part of a blood oxygenator or a cardioplegia unit. It is particularly suitable for such applications since the annularly corrugated tubing has an increase in surface area per unit length. When the heat exchanger is used for such biomedical applications it is essential that the flow of blood through the heat exchanger remain in the laminar range to avoid undue frothing of the blood. Since the amount of heat transfer is substantially proportional to the surface area, the improved heat exchanger of the present invention, by increasing the surface area per unit length of the tube, makes it possible to obtain substantially the same degree of heat transfer at a lower flow rate. Alternatively, a heat exchanger (made in accordance with the present invention) can have a smaller overall volume than a heat exchanger formed from a twisted helical tube of other prior art construction yet still have comparable performance. Thus, the improved performance of the heat exchanger of the present invention overall requires that a lesser volume of blood need be removed from the patient's body during use of the blood oxygenator or cardioplegia unit.

An additional benefit from the use of annularly corrugated tubing in such biomedical applications is the reduced fill volume for the blood flow passages when all other dimensions remain constant. Since the annularly corrugated tubing occupies more volume than comparably sized helical twisted tubing necessarily

there is less space for blood to flow. Since the increased surface area of the annularly corrugated tubing results in increased heat transfer there is no corresponding degradation in heat exchange performance although a smaller volume of blood is present in the biomedical unit.

The above brief description as well as further objects, features and advantages of the present invention will be more fully understood by reference to the following detailed description of the presently preferred, but nonetheless illustrative, heat exchange assembly in acordance with the present invention when taken in conjunction with the accompany drawings, wherein:

FIG. 1 is a side elevation of a tube-in-tube heat exchanger according to the present invention shown in partial cross-section;

FIG. 2 is a cross-sectional detail of FIG. 1, taken generally along the line 2-2 thereof looking in the direction of the arrows;

FIG. 3 is a plan view of a second embodiment of the present invention in a tube-in-tube heat exchanger configuration shown partially in cross-section;

FIG. 4 is a side elevational view of a further embodiment of the present invention in a coil and shell heat exchanger configuration shown partially in cross-

section;

FIG. 5 is a cross-sectional view of the embodiment of FIG. 4 taken generally along the line 5-5 thereof and looking in the direction of the arrows; and

FIG. 6 is an elevational view of a further embodiment of the present invention in a shell and tube heat exchanger configuration shown partially in cross-section.

Referring now to the drawings and in particular to FIGS. 1 and 2 there is shown a basic configuration of a tube-in-tube heat exchanger made in accordance with the present invention generally designated by the reference numeral 5. A first, inner tube 10 is located within a second, outer tube 20 having an interior passage 21. Inner tube 10 is formed with a series of annular corrugations 12, having troughs 13 and associated ridges 14 having a diameter less than the diameter of passage 21. A first fluid 16 passes therethrough in a first direction designated generally by arrow 18.

Outer tube 20 is generally cylindrical, and attached to a feeder tube or inlet 22 and an exit tube or outlet 24 by connectors 26 and 28 respectively. A second fluid 30 passes through feeder tube 22 into connector 26 in the direction designated by arrow 32, and follows feeder tube 22 to connector 28, and there exits from exit tube 24 in the direction designated generally by arrow

34.

As best illustrated by FIG. 2, the inner tube 10 comprises an alternating series of raised and lowered portions forming the annular corrugations. The manufacture of annularly corrugated tubing is well known, and may be accomplished, for example, by rolling or finger forming. Methods for manufacturing such tubing are described in U.S. Patents Nos. 2,845,988 (Andersen); 2,864,591 (Frink); and 2,913,009 (Kuthe).

It will be appreciated by those of ordinary skill in the art, that either first fluid 16 or second fluid 30 could be the warmer, that the indicated opposing flow of the subject fluids is illustrative only, that both fluids may flow in the same direction, in that either may be at rest at some point and that the specific configuration of feeder tube 22 and exit tube 24 shown may be varied.

Figure 3 illustrates another embodiment of the invention, wherein elements corresponding generally to those of FIGS. 1 and 2 are indicated by similar numerals with the prefix "3" added thereto (e.g., first fluid 316).

The configuration of FIG. 3 is often utilized in refrigeration systems, wherein second fluid 330 is the primary fluid (e.g., potable water, air) to be cooled by refrigerant 316. This embodiment has been discovered also to have particular utility for condensers, as the

annular grooves allow the formation of droplets therein.

A third embodiment of the invention is illustrated in FIGS. 4 and 5, in which the elements similar to those shown in FIGS. 1 and 2 have been identified with the prefix "4" followed by the corresponding reference numeral (e.g., first fluid 416). This configuration of the present invention has particular utility as a blood oxygenator or cardioplegia unit when the additional known elements are added (by Spurgers). This embodiment will be particularly described as such a device, although, as it will be appreciated, this configuration has other uses as a heat exchanger.

When the embodiment is used for such end use, second fluid 430 would be blood, and first fluid 416 would be coolant, generally tap water. The configuration comprises an inner tube 410 carrying coolant 416 disposed within a shell (outer tube) 420 through which the second fluid, blood 430, passes. Inner tube 410 is helically wound about a center body 440, which occupies the central volume of shell 420 to restrict the blood flow and thus ensure that the blood 430 passes close to the cooling inner tube 410. Oxygenation of the blood will be performed by a Spurger (not shown) in the bottom of the shell 420 in known fashion.

FIG. 5 shows the arrangement of centerbody 440 which may be solid or hollow. The outer surface of centerbody 440 and the inner surface of shell 420 define

a flow path for the second fluid 430. Since the second tube 410 is located in the flow path, the second fluid 430 must flow through the small areas between adjacent annular corrugations on the surface of inner tube 410 and the inner surface of shell 420 in a direction parallel to the annular corrugation. Such restricted flow path results in much improved heat transfer.

When in a coil and shell arrangement, the added flexibility of the annularly corrugated tube permits the inner tube 410 to be wraped more completely about the centerbody 440. This results in several key benefits.

First, more inner tubing 410 may be placed in the same volume of shell. This, taken together with the increased surface area of the unit length of inner tube (resulting from the annular corrugation configuration, as described above) drastically increases the heat transfer performance of the device. More importantly, the same amount of cooling may be performed by a smaller device. Thus, when the present invention is used as a blood oxygenator or cardioplegia unit, the absolute minimum volume of blood need be removed from the patient's body. When the patient is a child, the need to remove a small volume of blood is increased.

Other important features of the invention configuration result in further benefits.

Since the flexibility of the tube permits the tight winding of the inner tube 410 about the centerbody

440, the similar corrugations 412 face substantially parallel to the flow direction 432, 434 of the blood 430 (see FIG. 5). Such configuration of the inner tube results in less flow resistance than known prior art devices.

Furthermore, a flow path parallel to the annular corrugation results in much less turbulance within the shell. In a blood oxygenator, this turbulance may lead to undesirable agitation and "frothing" of the blood. Thus, when the present invention is used as a blood oxygenator or cardioplegic device it may be possible to pass the blood through the device while still attaining the same degree of heat transfer.

As a further embodiment, the device pictured in FIG. 6 illustrates a tube in shell arrangement. The elements common to those shown in FIGS. 1 and 2 have the prefix "6", (e.g., first fluid 616).

In this embodiment, a plurality of inner tubes 610 are positioned within shell (outer tube) 620. To ensure the flow of first fluid 616 about the shell 620, a series of alternating baffles 650 are disposed along its length. These baffles direct the flow of second fluid 630 in an "up/down" flow pattern, so that the flow is generally parallel to the annular corrugation 612. Thus, heat exchange performance is optimized.

It will also be noted tht, as described above, flat lands 660 may be disposed at predetermined locations

along the length of inner tube(s) 610, and that these lands may serve the advantageous purpose of providing a place to which baffles 650 may be secured to inner tube 610.

As will be readily apparent to those skilled in the art, the above description represents a preferred but nonetheless illustrative embodiment of the apparatus and method of the present invention, which may be realized in other specific forms without departing from its spirit or essential characteristics. Therefore, the full scope of such invention is to be measured by the appended claims, giving thereto the full range of equivalence which comes within the meaning and range of the claims.

CLAIMS

1. A fluid heat exchanger (5) comprising: a first tube (20) having a passage (21) therein for carrying a first fluid (30) in a first direction (32, 34); a second tube (10) disposed within said passage, and having a plurality of annular corrugations (12) thereon, for carrying a second fluid (16) in a second direction (18); inlet means (22) connected to a first end (26) of said first tube for introducing said first fluid to said first tube; and outlet means (24) connected to a second end (28) of said first tube, for discharging said first fluid therefrom.

2. The fluid heat exchanger of Claim 1, wherein the surface area of a portion of the second tube (10) having annular corrugations (12) thereon is in the range of 40-100% greater than an equal length of smooth-wall tube.

3. The fluid heat exchanger of Claim 1 or Claim 2, wherein the outer diameter (14) of the annular corrugations (12) is less than the inside diameter (21) of the first tube (20).

4. The fluid heat exchanger of any preceding Claim, wherein the plurality of annular corrugations (12) comprises the entire length of the second tube (10).

5. The fluid heat exchanger of any of Claims 1 to 3, wherein the second tube (612) further comprises at least one flat land portion (660) thereon.

6. The fluid heat exchanger of any preceding Claim, wherein [the second tube has] inlet means are connected to a first end of the second tube (10) for introducing the second fluid (16) to the second tube; and outlet means are connected to a second end of the second tube for discharging the second fluid therefrom.

7. The fluid heat exchanger of any preceding Claim, wherein the first and second tubes (20, 10) are coaxial.

8. The fluid heat exchanger of any preceding Claim, wherein said first direction (32, 34) opposes said second direction (18).

9. The fluid heat exchanger of any of Claims 1 to 7, wherein said first direction (32, 34) and said second direction (18) are the same.

10. The fluid heat exchanger of any preceding Claim, wherein the first tube (320) and the second tube (310) are coiled.

11. The fluid heat exchanger of any of Claims 1 to 9, wherein a plurality of second tubes (610) are disposed within the first tube (620).

12. The fluid heat exchanger of Claim 11, wherein a plurality of baffles (650) are disposed within the first tube (620).

13. The fluid heat exchanger of Claim 12, wherein each of said plurality of second tubes (610) has at least one flat land portion (660), and each of the baffles (650) is secured to the plurality of second tubes at flat land portions thereof.

14. A fluid heat exchanger comprising: a first tube (420) having a passage therein for carrying a first fluid (430) in a first direction; a second tube (410) disposed within said passage, and having a plurality of annular corrugations (412) thereon, for carrying a second fluid (416) in a second direction; inlet means (432) connected to a first end of said first tube, for introducing said first fluid to said first tube; outlet means (434) connected to a second end of said first tube, for discharging said first fluid therefrom; and a centerbody (440) centrally disposed within said first tube; and wherein said second tube is wrapped around said centerbody.

15. The fluid heat exchanger of Claim 14, wherein a portion of said annular corrugations (412) are disposed generally parallel to the axis of the first tube (420).

16. The features herein described, or their equivalents, in any patentably novel selection.

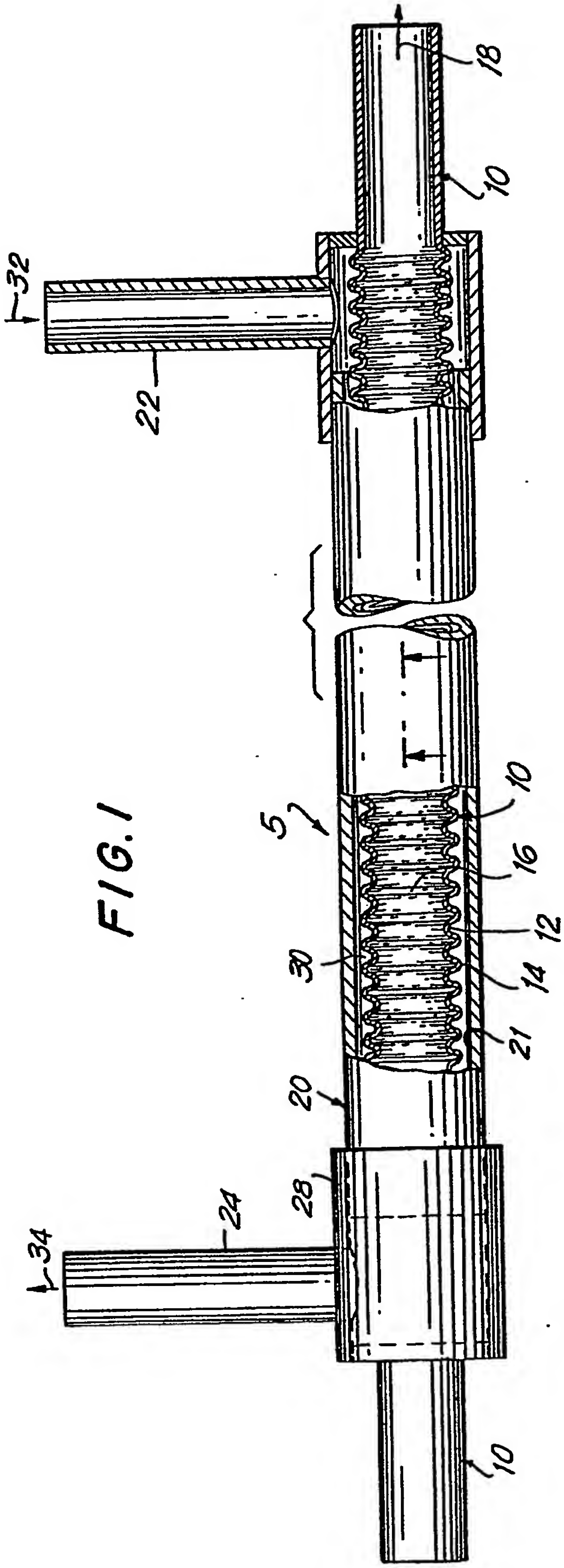


FIG.1

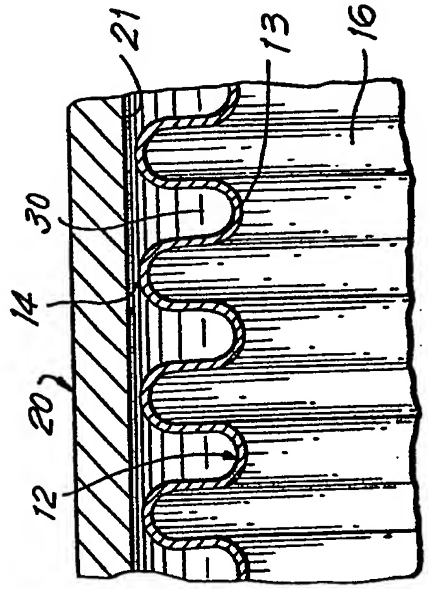
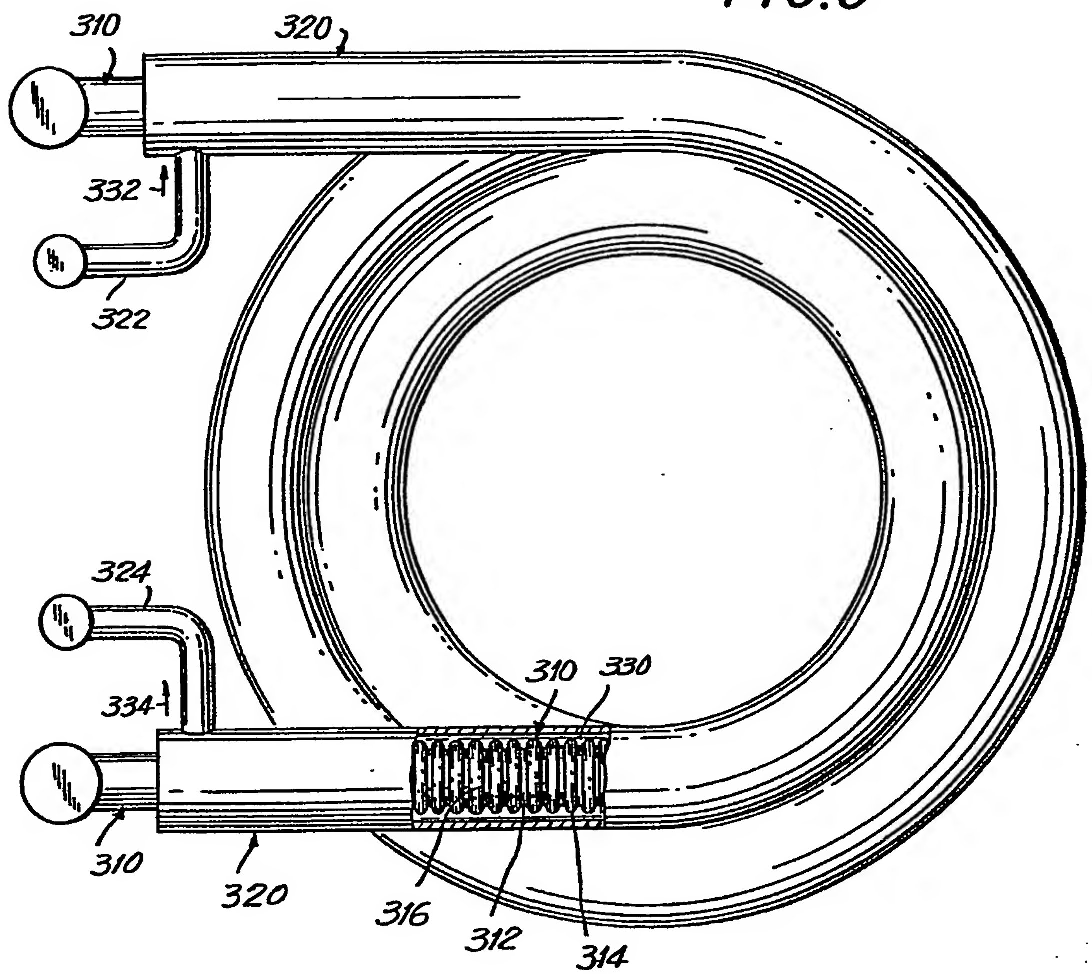


FIG.2

FIG.3


310
320
332
322
324
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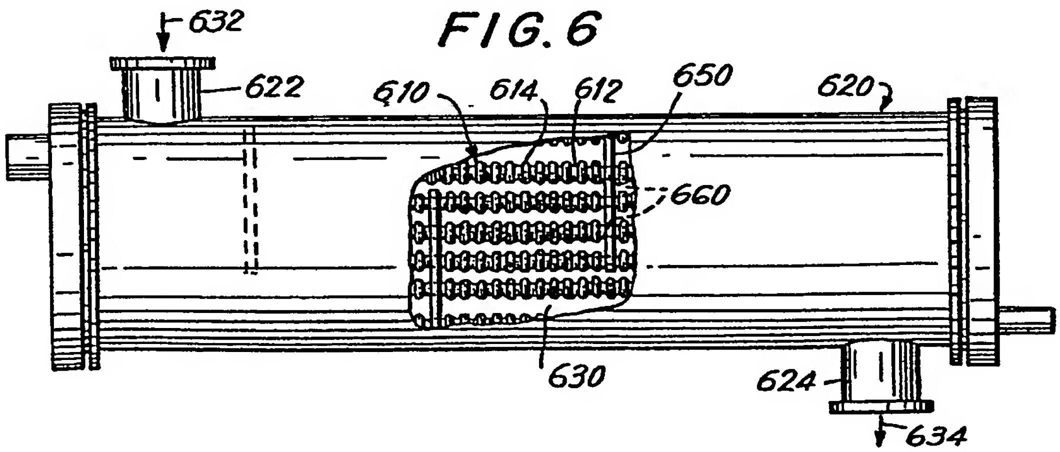
314

FIG.6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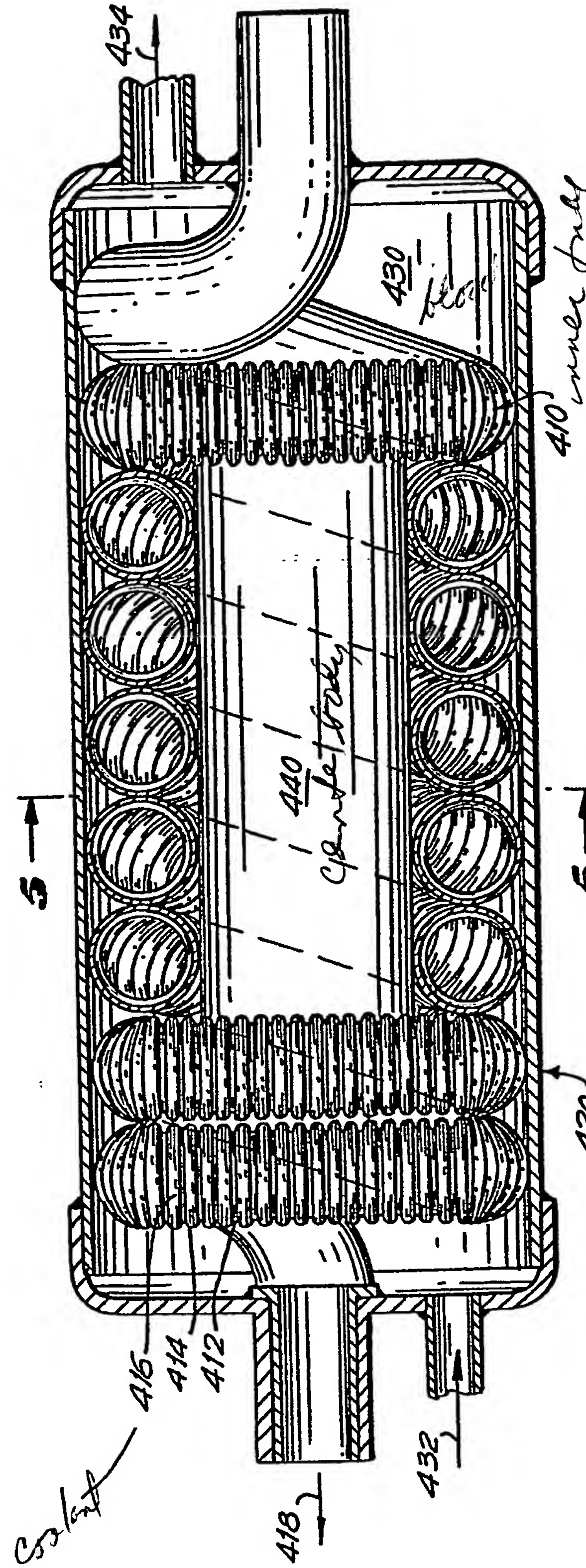
634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430
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inner tube
440
5
5
420
shell
416
414
412
418
432
Coolant

FIG. 4

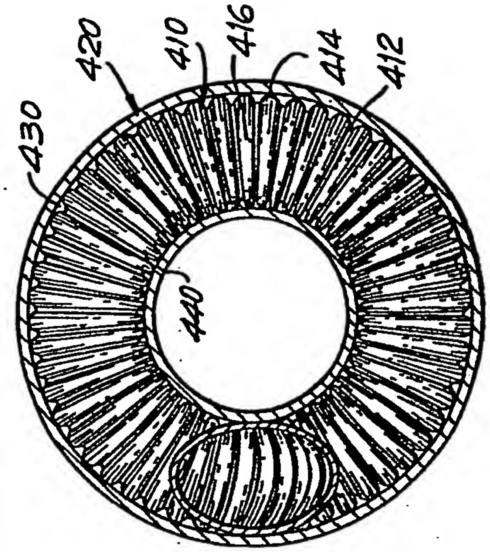
420
410
416
414
412
430
440

FIG. 5

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EUROPEAN SEARCH REPORT

Application number

EP 83 30 6295

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	US-A-4 270 601 (LANCASTER) * Whole document * ---	1-4,6,7,9	F 28 D 7/10 F 28 F 1/08
X	FR-A-2 322 345 (MULTIFLUID-ENERGIE) * Pages 3,4; figure 1 * ---	1-4,7	
A	FR-A-2 404 824 (KOMB. FORT. LANDMASCHINEN) * Page 4, claim 3; figures 2,3 * ---	1-4,7-9	
D,A	FR-A-1 176 522 (CALUMET & HECLA) * Page 1, left-hand column; figures 1,3 * ---	5,13	TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
A	FR-A-1 499 286 (HACKETHAL) * Figures 1,7 * ---	10	F 28 D F 28 F
A	US-A-4 171 634 (PERKINS) * Figure 6 * ---	11,12	
A	DE-A-2 236 954 (ALFA ROMEO) * Page 10, last paragraph; page 11; figure 6 * ---	14	
A	US-A-3 267 997 (MATARESE) * Figure 7 * --- -/-	15	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	08-02-1984	SCHOUFOUR F.L.

CATEGORY OF CITED DOCUMENTS

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
A	US-A-3 219 106 (AHERN) ---		
A	US-A-3 921 708 (BRENNER) -----		
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)

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